Wind Profiler Signal Processing: Current and Future Technologies

Dan Wolfe **NOAA Environmental Technology Laboratory**

Steve Cohn **NCAR Atmospheric Technology Division**

Boulder, Colorado

daniel.wolfe@noaa.gov cohn@UCAR.edu

AMS Short Course on the Fundamentals of Boundary Layer Wind and Temperature Profiling using Radar and Acoustic Techniques, 8-9 February 2003, Long Beach, California

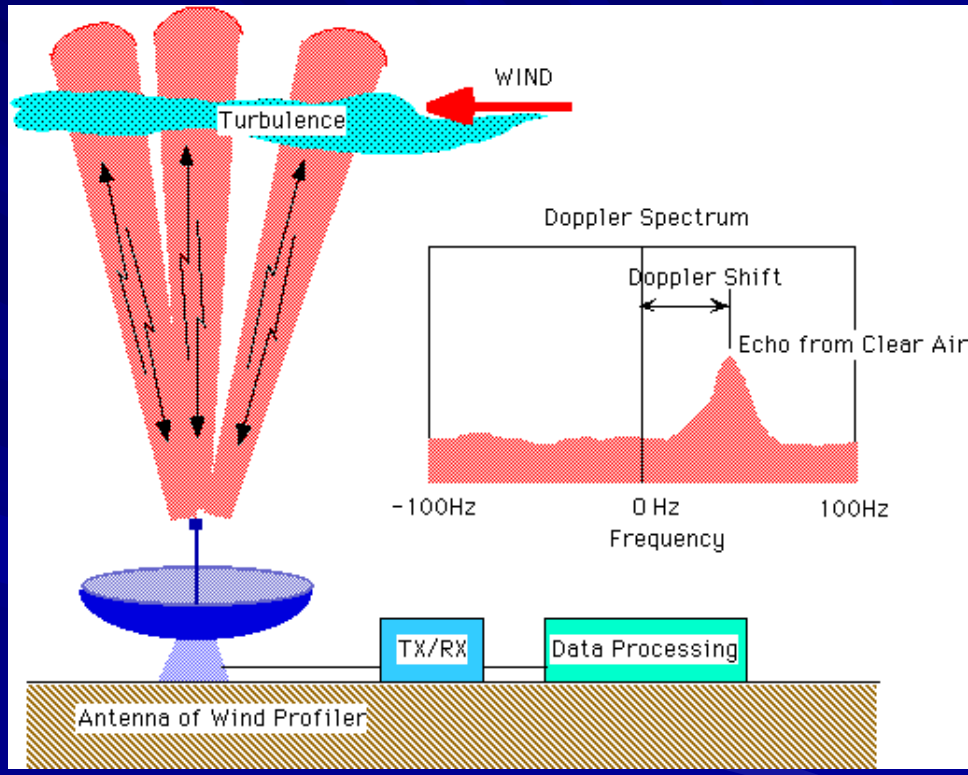
Outline

- Why do we need improved SP?
- Review existing processing
- NIMA
- SPS
- Additional Ideas
  - Wavelets, RIM
- Sodar Processing…..

Wind Profiler Wind Measurement

Measures the ***radial*** wind component in 3 or 5 directions.

Combines these components to find the vector wind

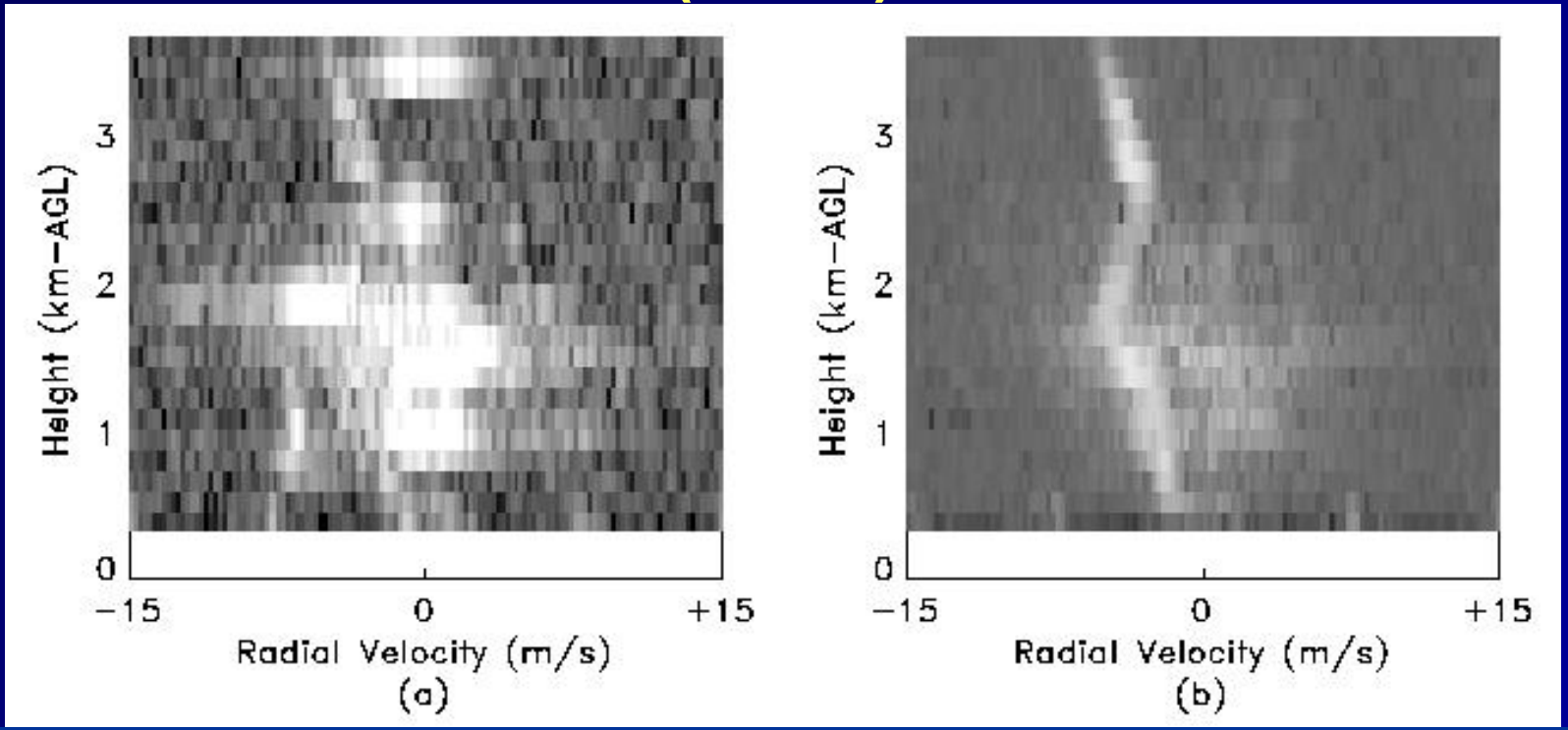


http://www-das.uwyo.edu/~geerts/cwx/notes/chap15/profiler.html

“Standard Processing”

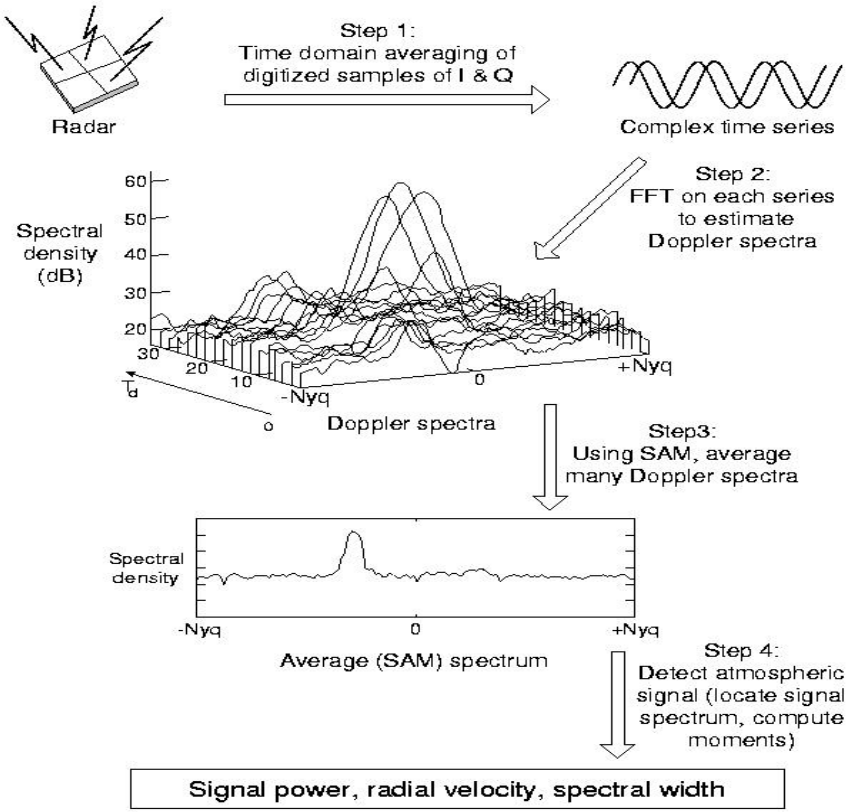
- Coherent Integration — *Affects data rate, Nyquist frequency, SNR*
- Windowed FFT — *Broadens spectral features*
- **Spectral Averaging** — *Reduces data rate, improves detectability*
- Signal Identification — *Maximum Peak*
- Wind Finding — *Consensus averaging*
- Wind QC — *Removes fliers on avg’d winds*

SATISTICAL AVERAGING METHOD (SAM)
Intermittent Clutter Rejection Algorithm (ICRA)



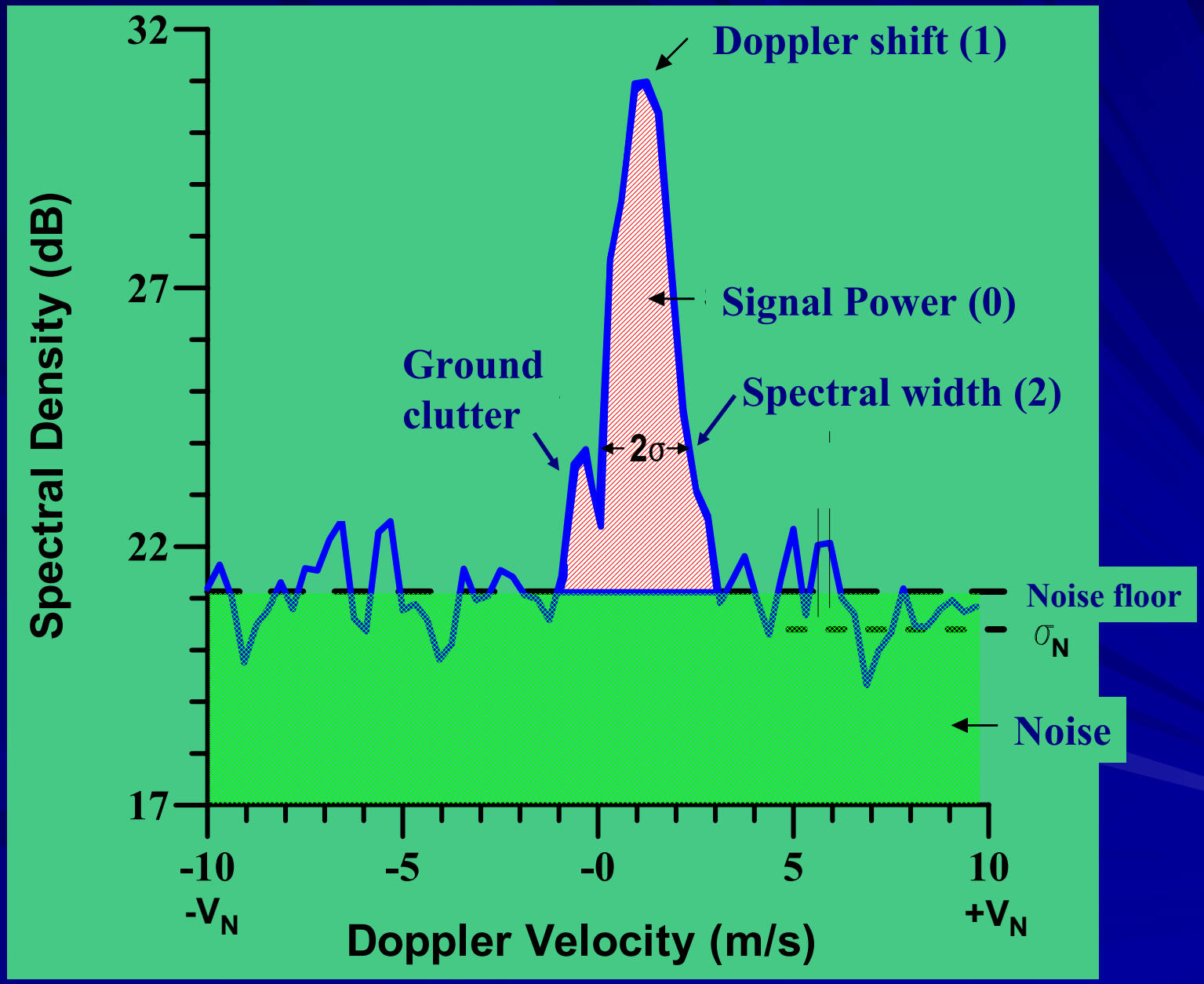
Merritt D.A. 1995 JTech 12 US Patent 5,568,151

Statistical Averaging Method



Merritt D.A. 1995 JTech 12 US Patent 5,568,151

Moments of the Average Doppler Spectrum



The Consensus Test

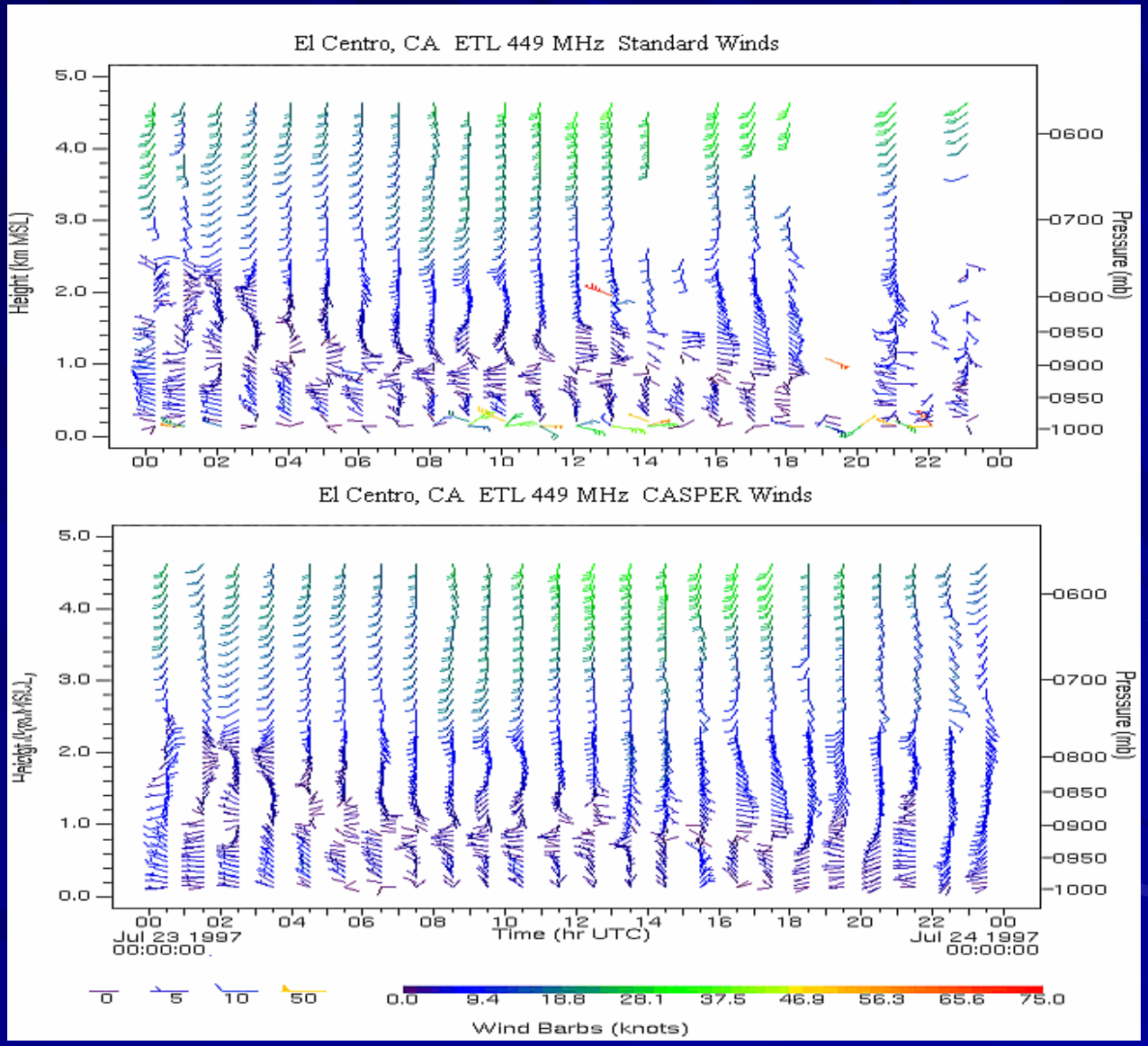
- Consensus Time (e.g. 30 min)
- Consensus Window (e.g. W=2 m/s)
- Consensus Threshold (e.g P=60%)

Can we find a window of W m/s that contains at least P (%) of the measured velocities?

- No….no value reported
- Yes…value reported is the mean of the points within the defined window

Winds Identification

Non-local analysis makes use of height and time continuity



Weber et al.,JTech 10 (1993)

Profiler Wind Measurement and QC:
The Problem:

How to best: *Generate Doppler spectra*
Find the moments of atmospheric signals
Combine these moments into wind and other derived information

In the presence of: *Low SNR*
Noise
Ground clutter
Moving clutter targets
Radio-frequency interference (RFI)
Aliasing

Generic Signal Processing

Signal Detection

- Discrimination between signal and noise. (Hildebrant/Sekhon)
- Are one or more non-noise signals present in spectrum?

Parameter Estimation

- What are the base parameters of the detected signal?
- Gaussian shaped spectrum of signals is often assumed

Signal Identification

- If more than one signal is detected, which one is due to the (clear-air) atmospheric return?
- What kind of a-priori information can be used to select it?
- Can unwanted contamination be effectively filtered out without affecting (biasing) the desired signal?

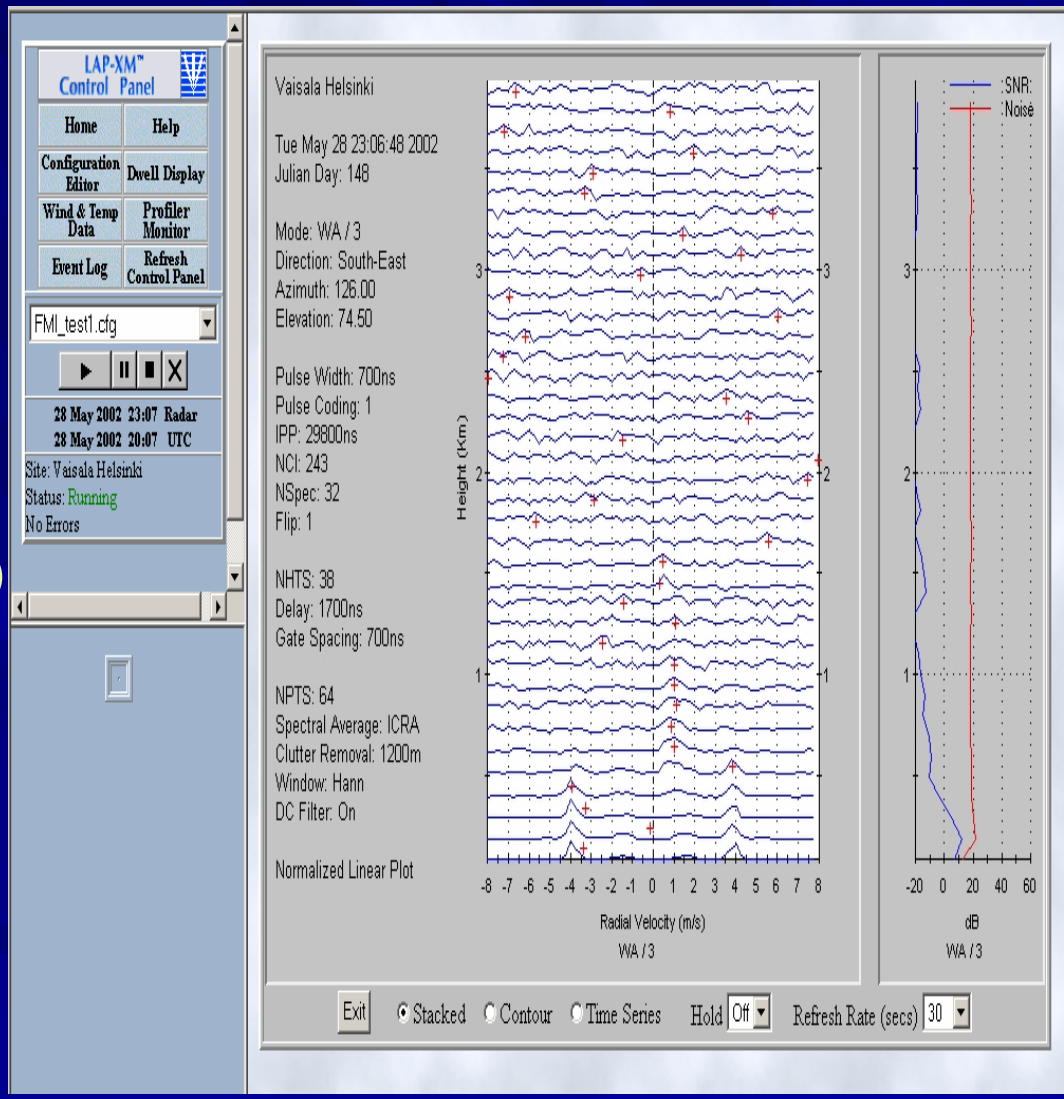
A-prior Information

There exist temporal and spatial continuities in a time series of spectral profiles which can be employed. Certain a-priori information such as the occurrence of power line radiation at 60 Hz and harmonics or the characteristics of fading clutter (e.g. magnitude, persistence in time and diminution with height) is useful in minimizing contaminating effects. Echoes backsacttered from the atmosphere exhibit continuity in time and height that can restrict the search of signal peaks to a certain part of the spectrum.

C.R. Cornish (1983) Parameterization of Spectra Workshop on Technical Aspects of MST-Radar Urbana, IL

Wind Profiler Challenges

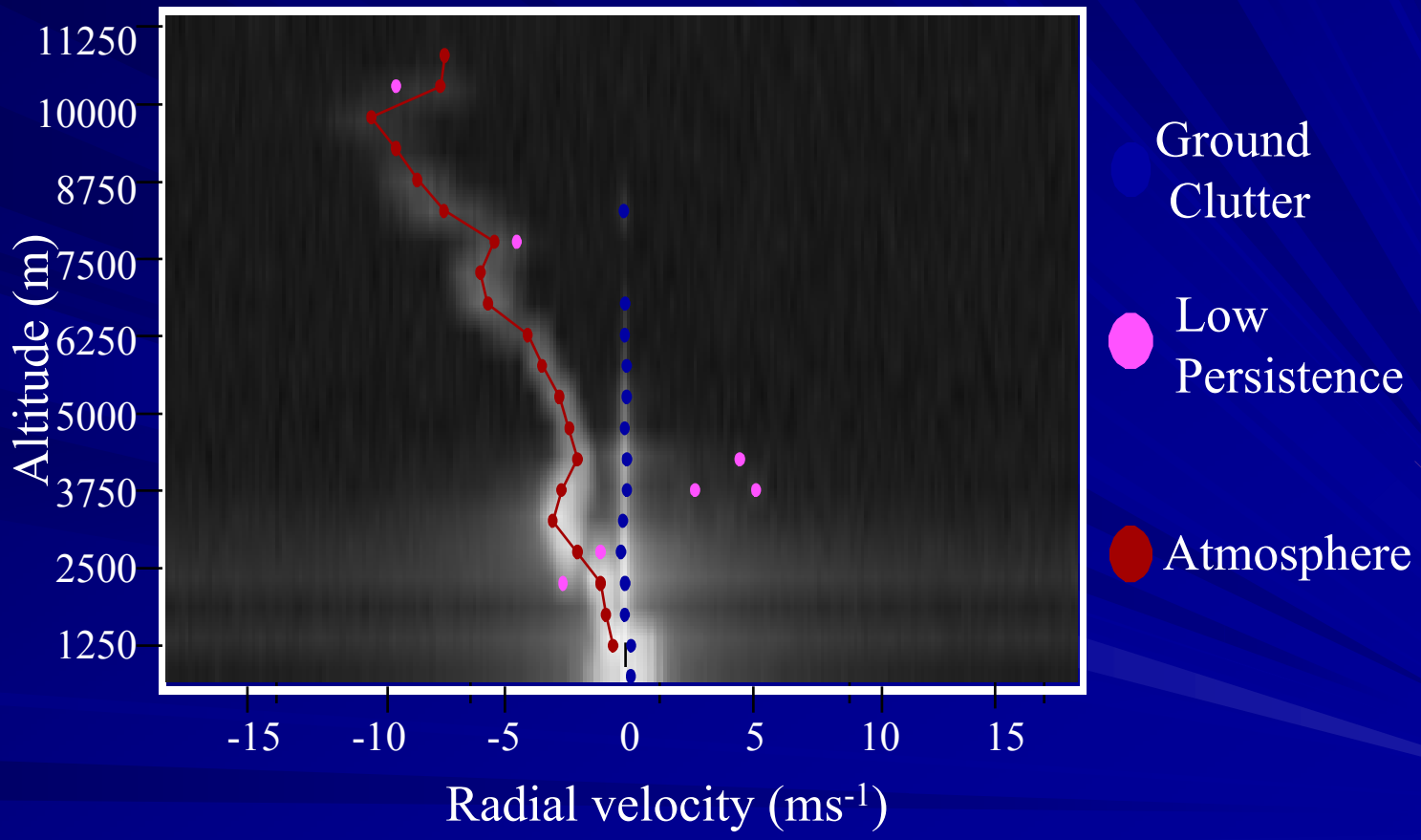
- Low SNR
- Noise
- Ground clutter
- Moving clutter targets (birds)
- Radio-frequency interference
- Aliasing
- Receiver saturation



"Where's the Signal??"

Spectral Signal Identification

Multiple-Peak Picking Algorithm (MPP)

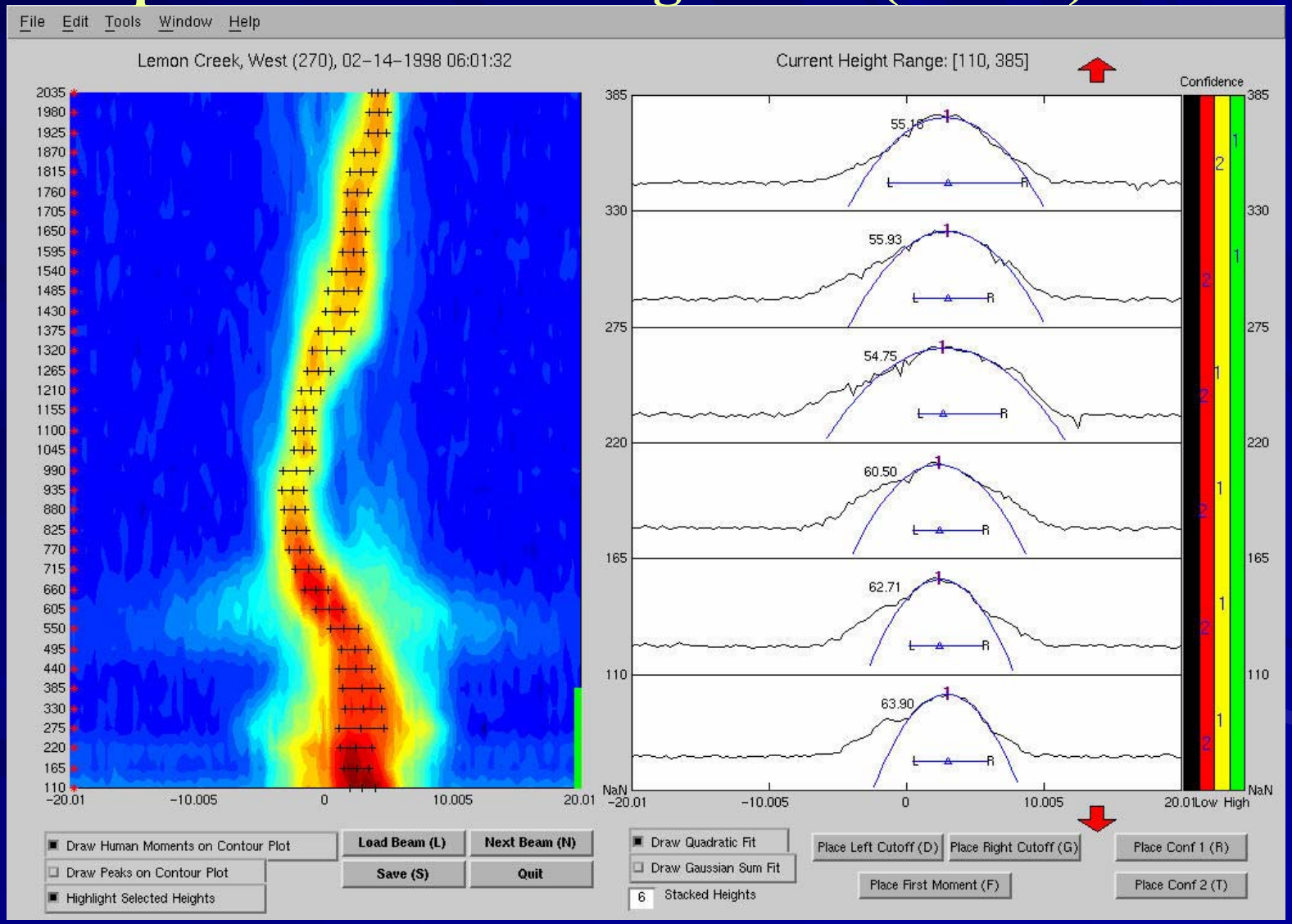


Clothiaux et al. JTech 11 (1994)

Image courtesy of T. Wilfong, NOAA/ETL

Fuzzy Logic: Global Image Processing

NCAR Improved Moments Algorithm (NIMA)

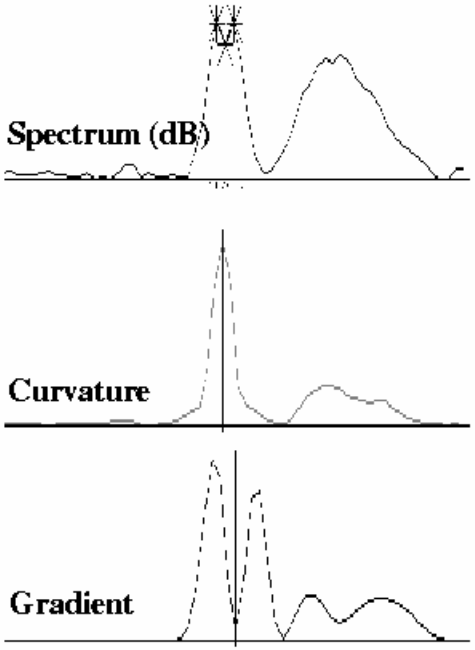


Cohn et al. 2001, JAM 40, 704-719

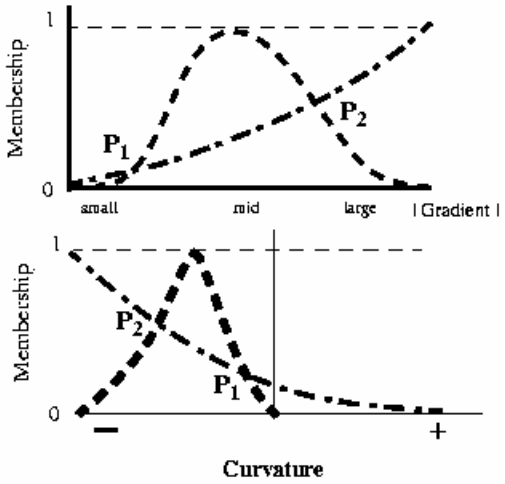
Fuzzy Logic: Global Image Processing

NIMA: Fuzzy Logic Based Spectral Moments

Find characteristics of local signal



Score features using Interest Maps



- Uses range as well as frequency continuity
- Delay applying any hard threshold
- Recognizes ground clutter characteristics
- Recognizes radio interference (RFI)
- Provides a "confidence" quality value

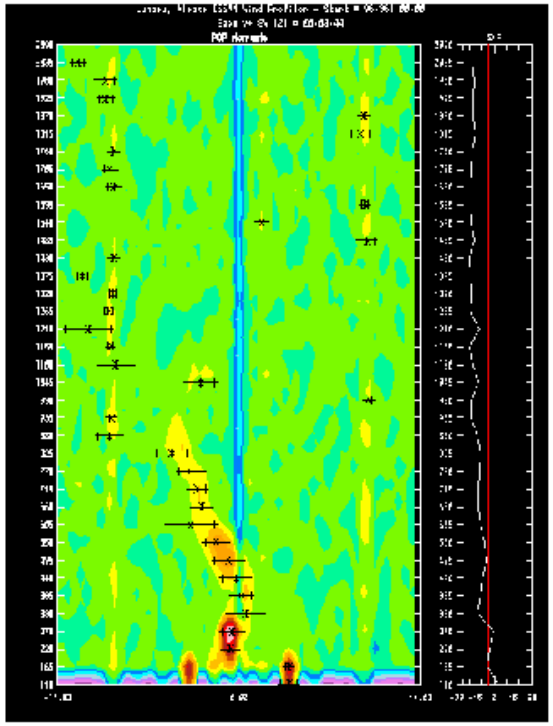
Cornman et al. 1998, JTECH 15, 1287-1305

Fuzzy Logic

NIMA

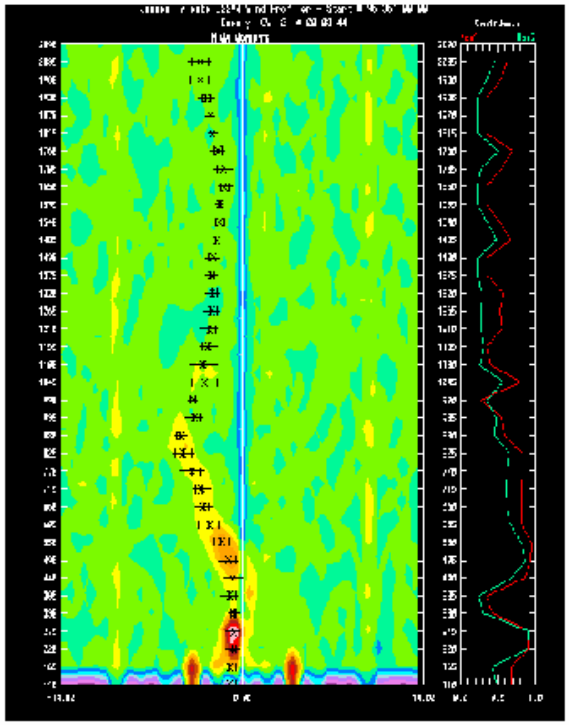
NIMA Result: Spectra with RFI and Recovery Spurs

Peak Picking Algorithm



BEFORE

NIMA

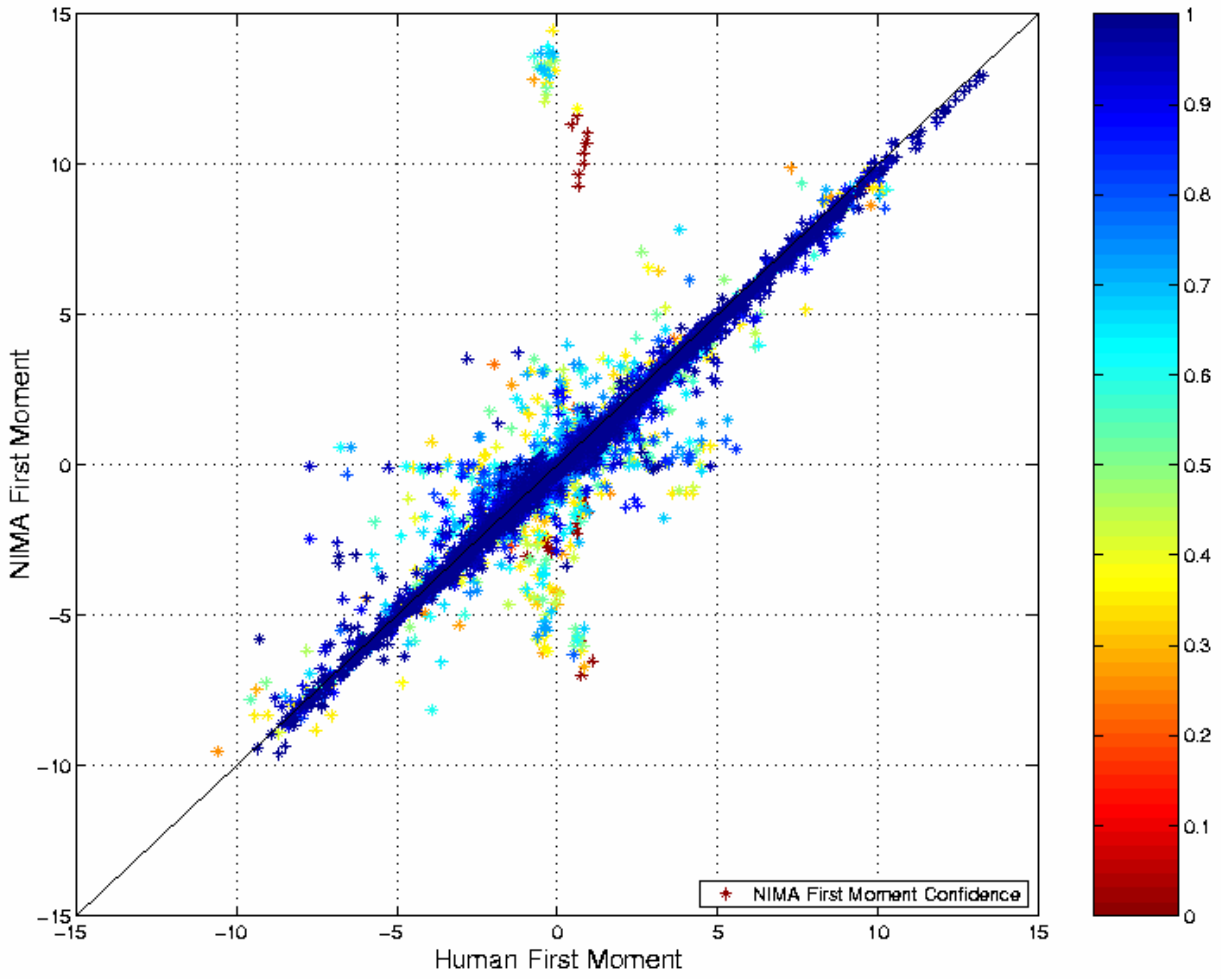


AFTER

NIMA First Moment (Radial Velocity) Comparison

NIMA

N=6270
R^2=0.857



Cohn et al. 2001, JAM 40, 704-719

NIMA Confidence Index

NIMA moment confidence depends on:

- **SNR**
- **“Reasonableness” of Gaussian fit to spectrum**
- **Continuity in height and time**
- **Spectrum noise statistics**
- **Closeness to spectrum region of clutter or RFI**
- **“Reasonableness” of calculated spectrum width**

Moments to Winds

NCAR Winds and Confidence Algorithm (NWCA)

Based on a linear wind field.

Tests assumptions for confidence estimate

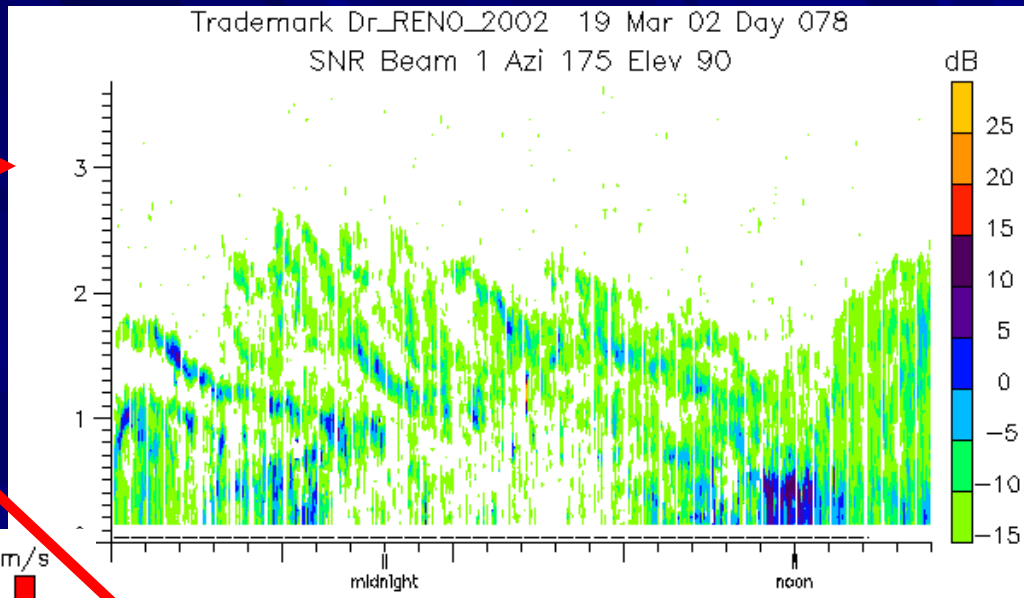
- ***Moments input is of good quality***
- ***Wind field is close to linear***
- ***Vertical wind has no horizontal shear***
- ***The wind field is stationary in time and space***

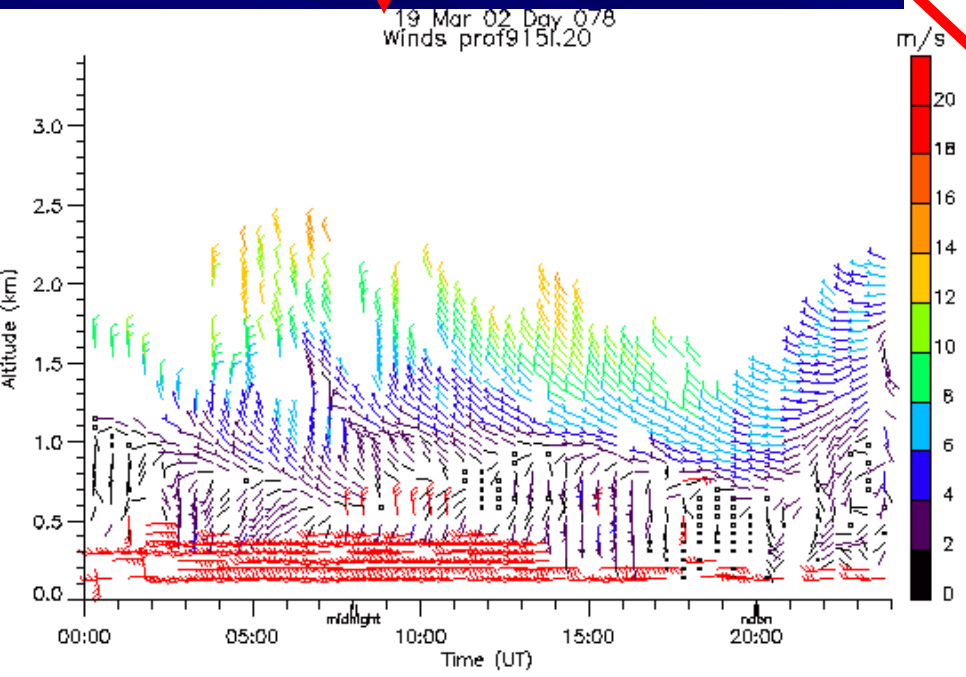
Standard Processing vs NIMA

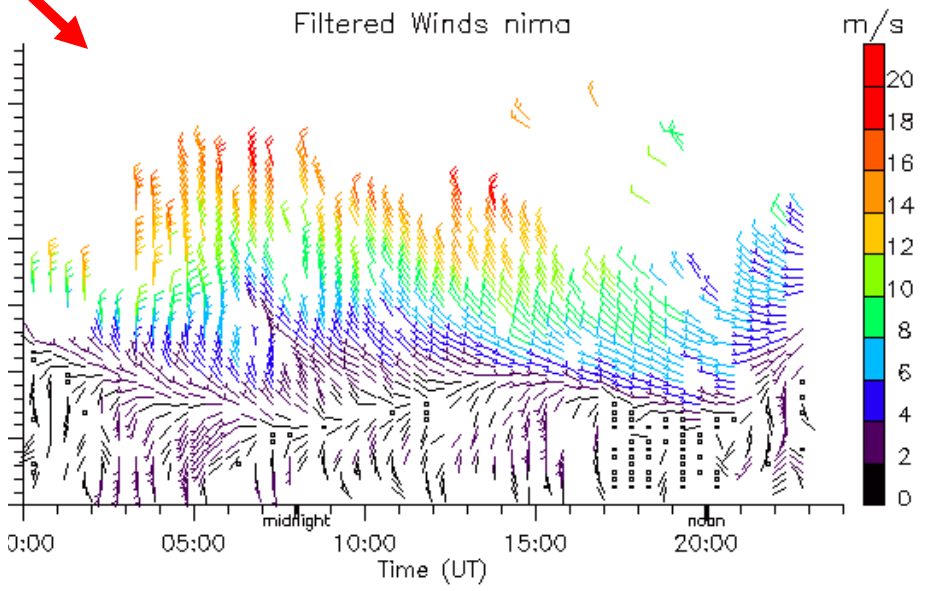
SNR

CNS

NIMA







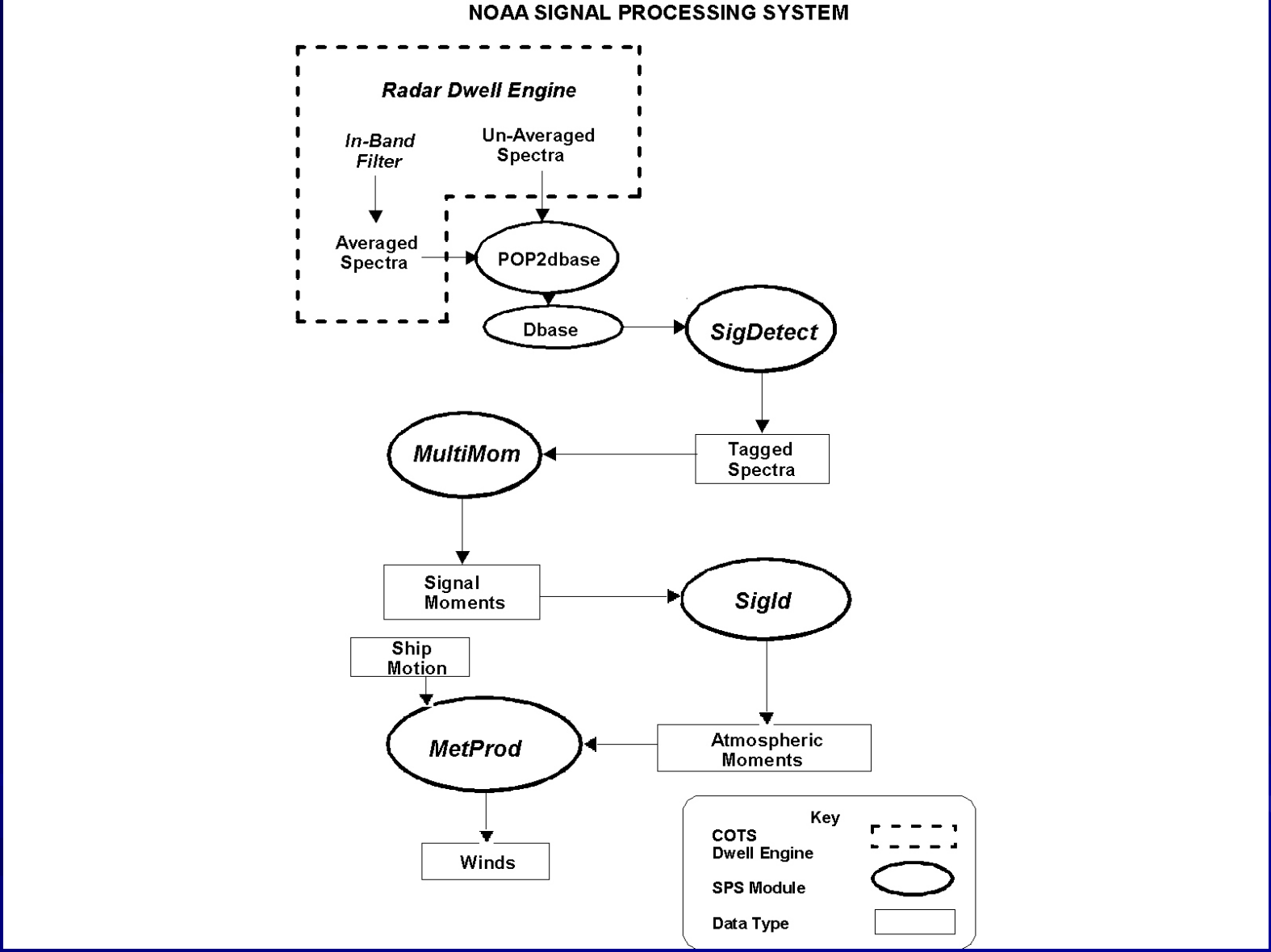
Juneau, Alaska: Looking to the Southeast

NCAR NIMA/NWCA

Juneau, AK

ISS Reno, NV

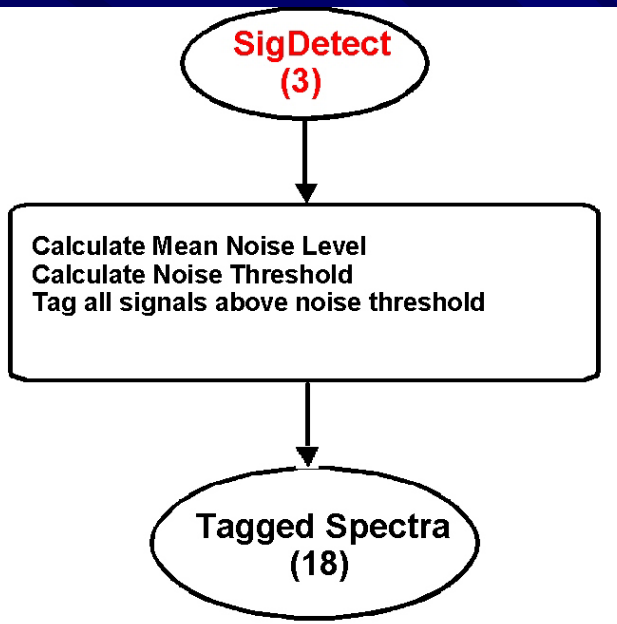
NOAA/ETL Signal Processing System (SPS)*

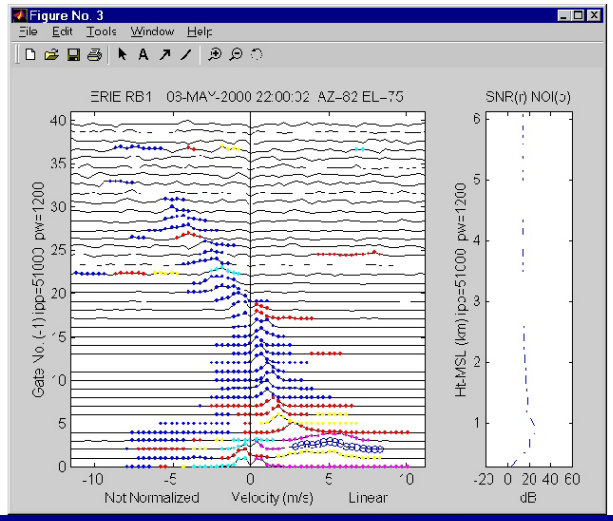


*CASPER…. Control and Signal Processing Engine for Radar

Wolfe et al. 2001 11th SMOI

Signal Detect





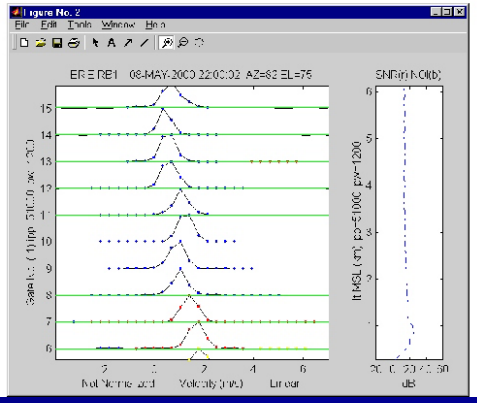
Multiple Moments

MultiMom (18)

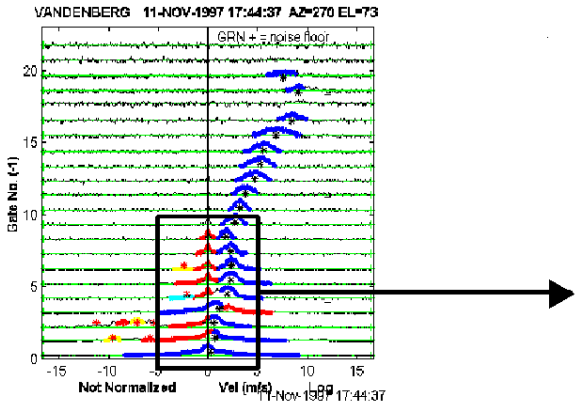
For Each signal (using least squares fit or centroid)
- Calculated Power (integrated)
- Calculated Doppler Velocity
- Calculate Spectral Width

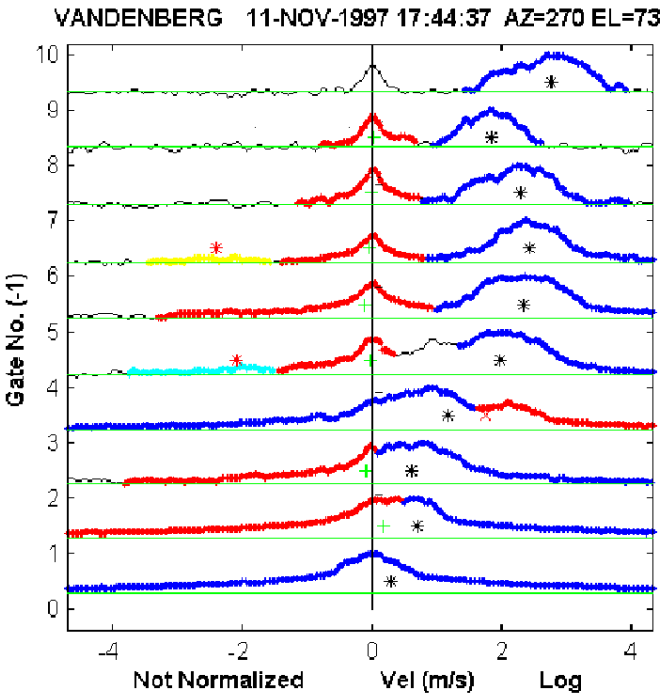
Calculate centric height for each range gate
Calculate accuracy and reliability estimates

Signal Moments (11)

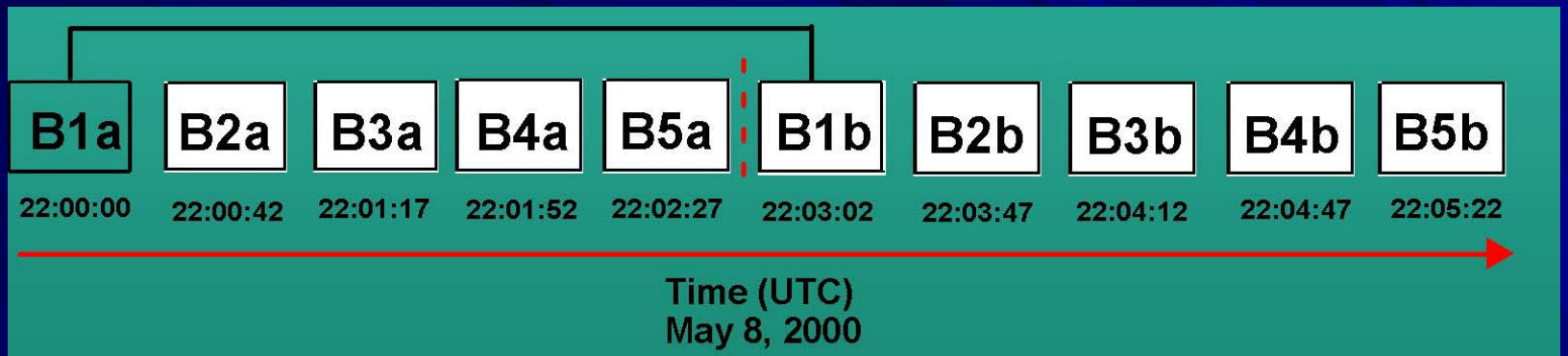


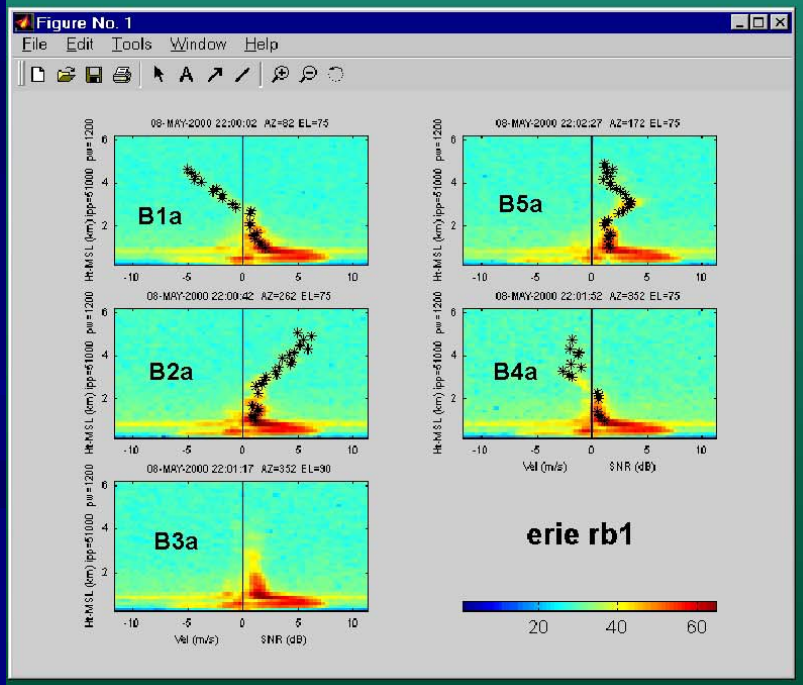
Overlapping Signals

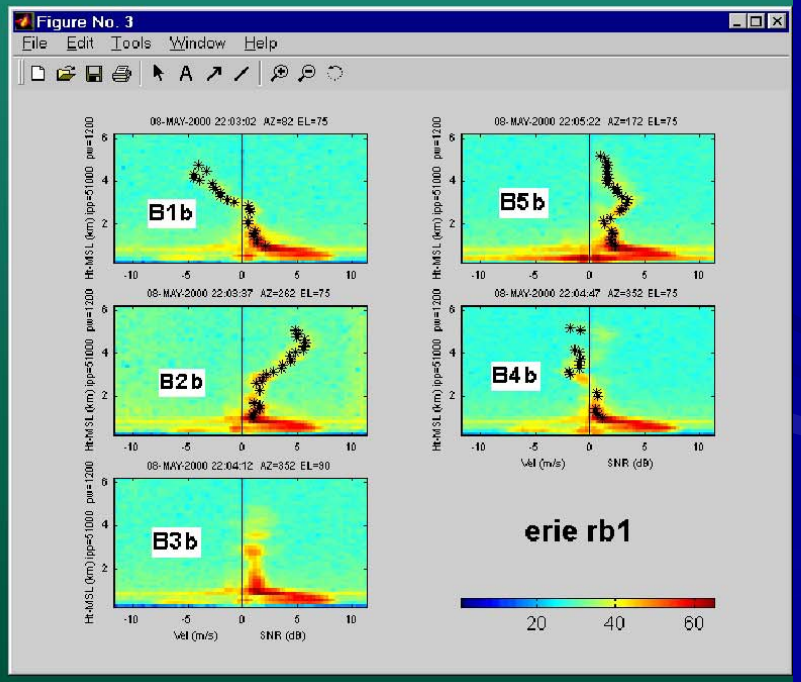




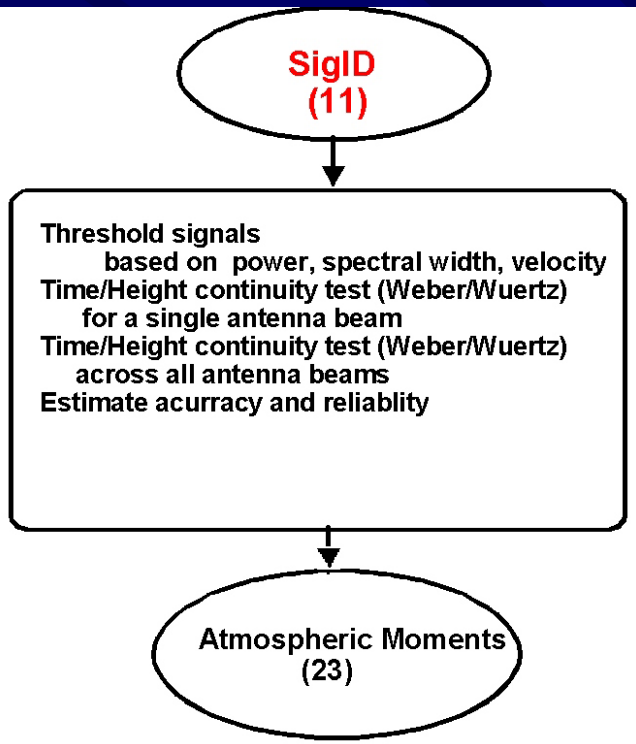
Multiple Beams.....

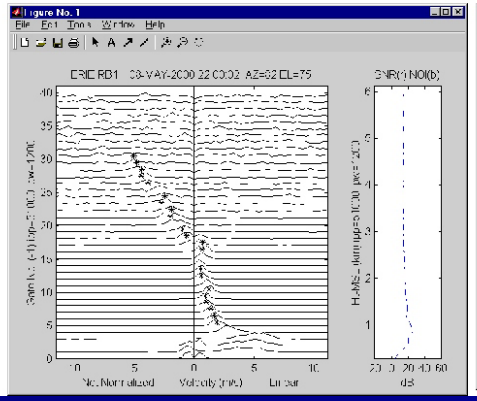


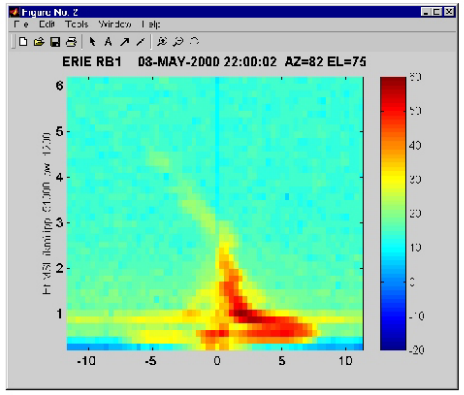




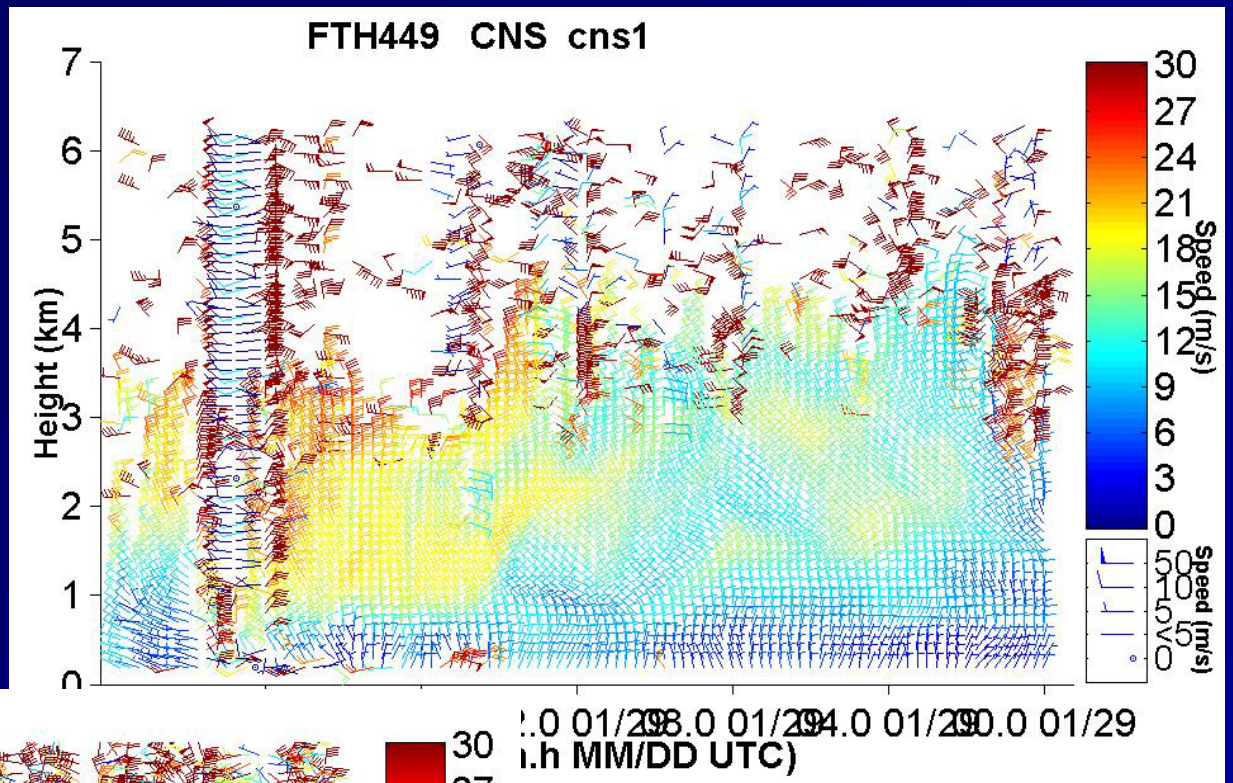
Signal Identification

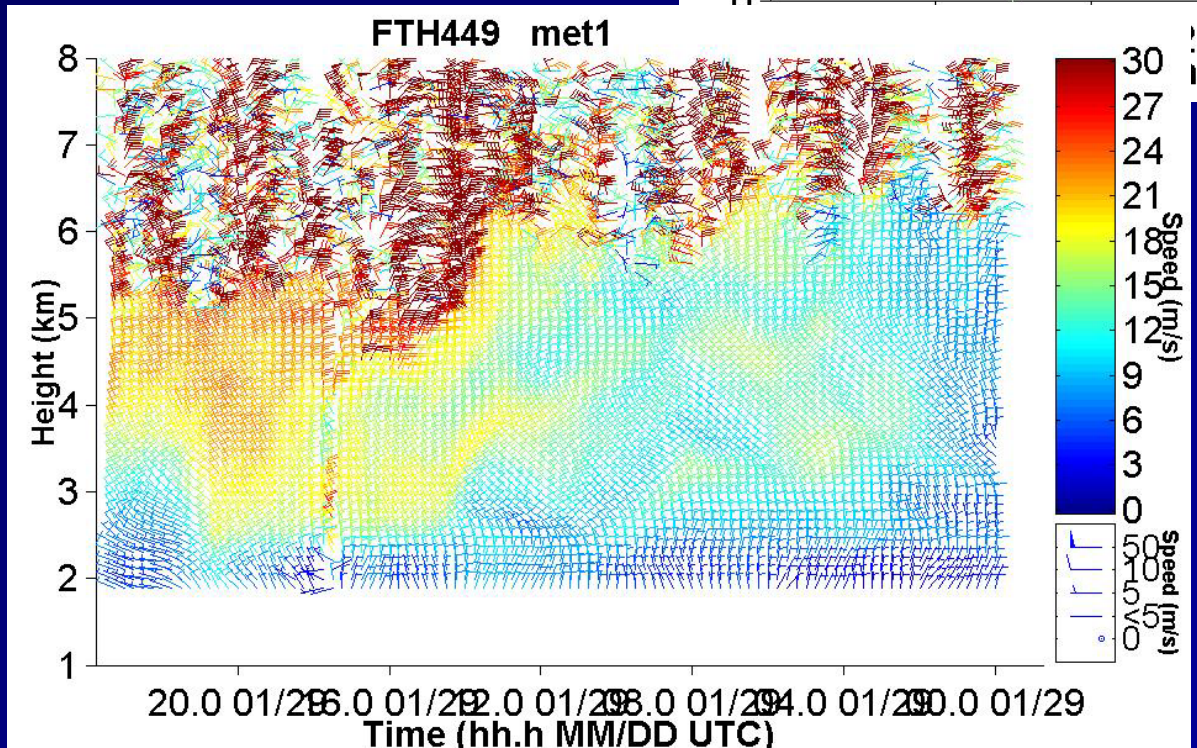






Meteorological Products

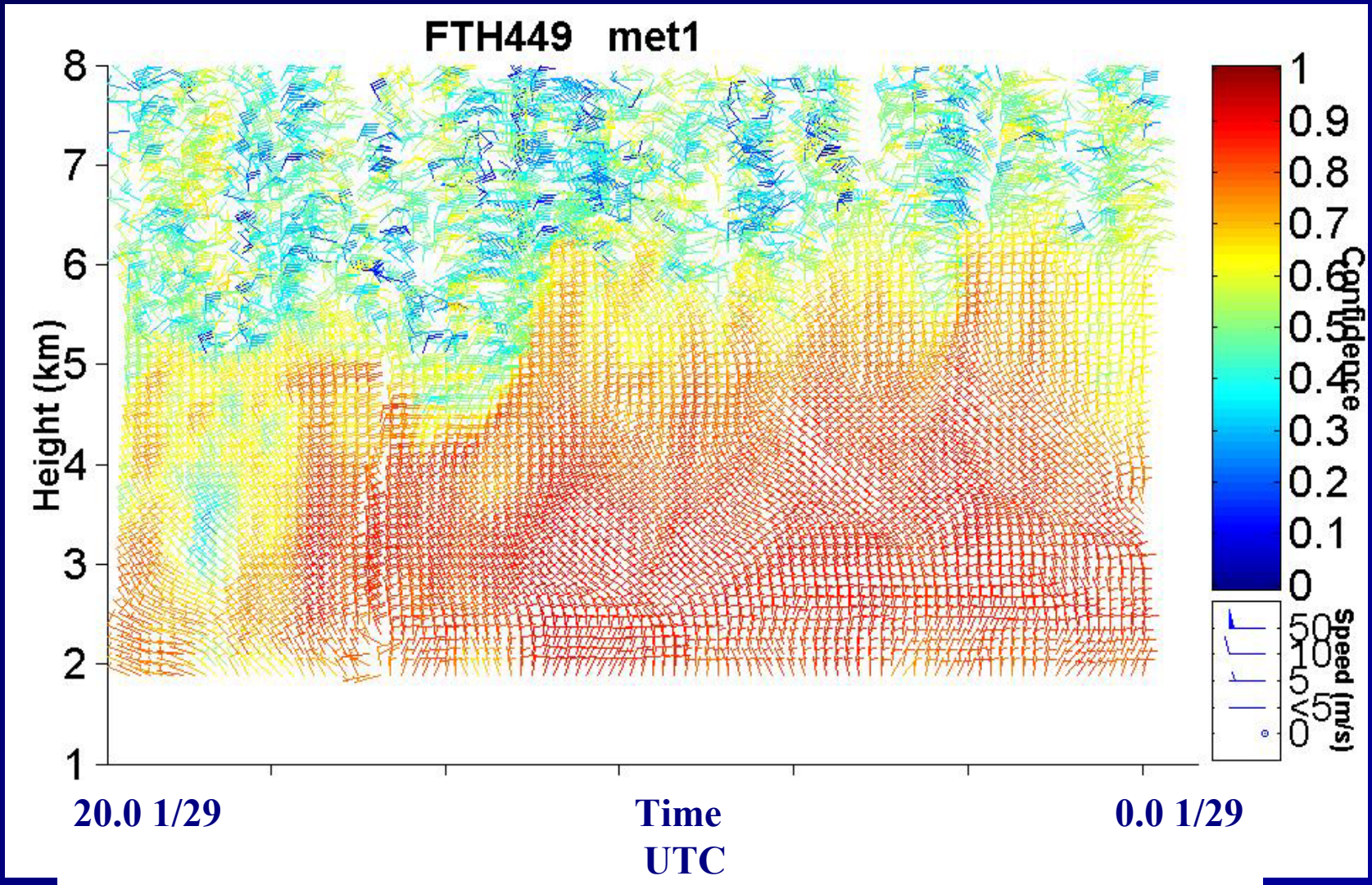




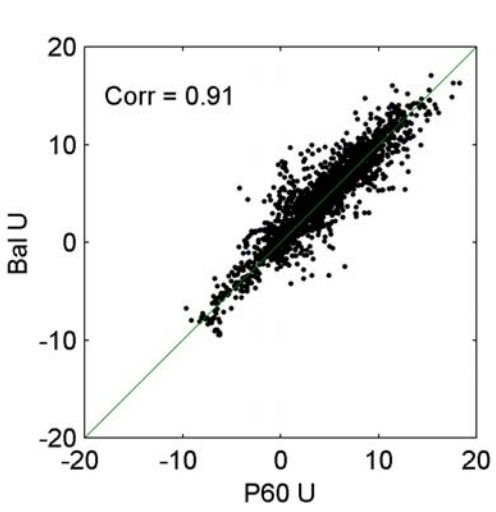
CNS

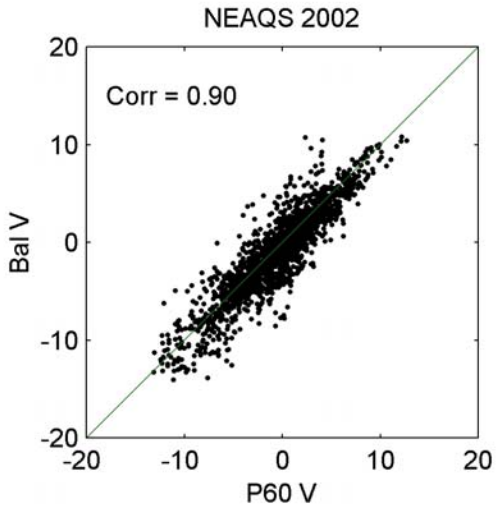
SPS

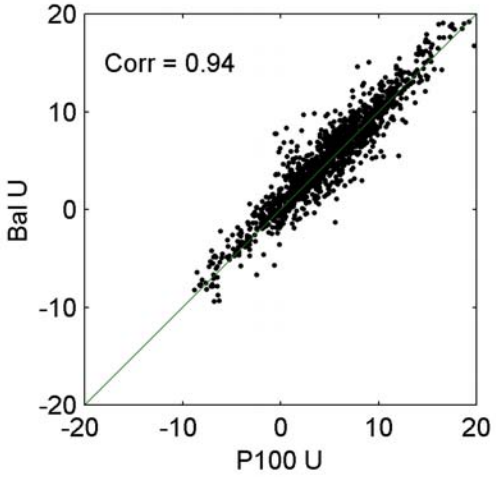
SPS Confidence Factor (0-1)

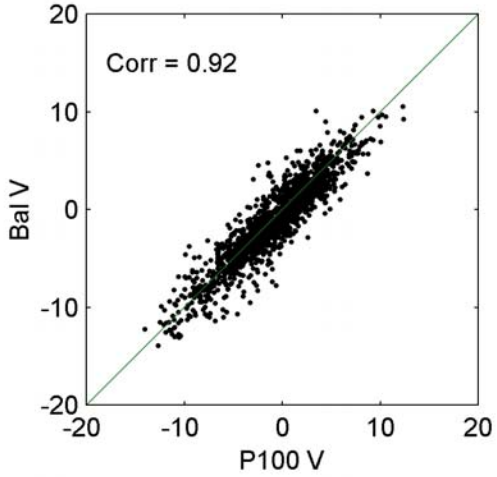


SPS vs Balloon









Wolfe et al. 2003 12th SMOI

“Algorithms”

Coherent Integration	Wavelet pre-processing No coherent integration Low-pass filter
Windowed FFT	No windowing for long time series.
Spectral averaging	Statistical Averaging Method (SAM-ICRA)
Signal identification	Multi-Peak Picking (MPP) ETL Signal Processing System (SPS) NCAR Improved Moments Algorithm (NIMA)
Wind finding	NCAR Winds and Confidence Algorithm (NWCA) ETL Signal Processing System (SPS) Weber/Wuertz (QC)

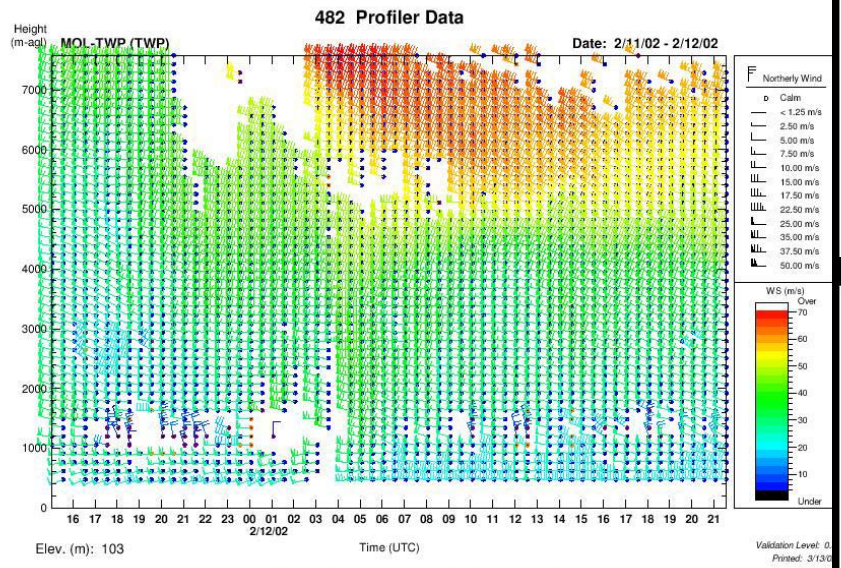
NOAA/ETL SPS

Ft Huachuca, AZ…TARS
http://www.etl.noaa.gov/technology/archive/fth/

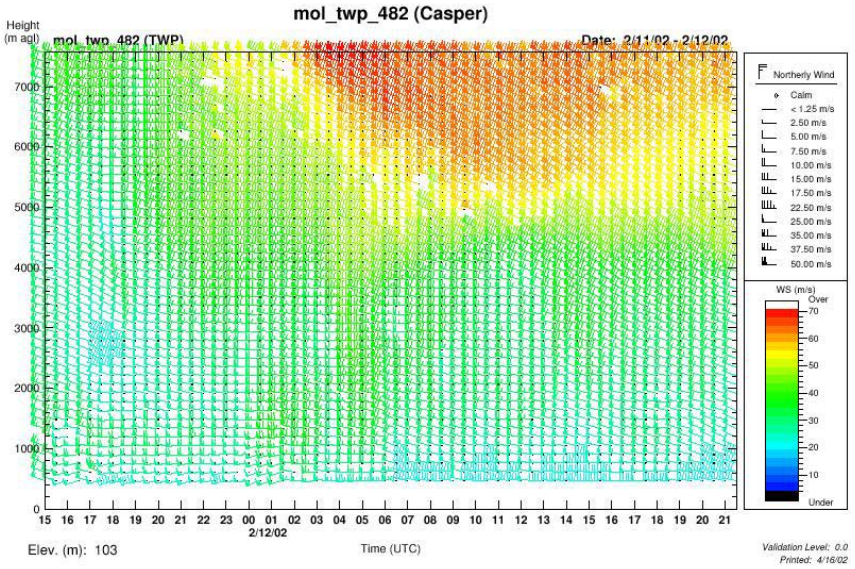
R/V Ronald H. Brown NOAA
http://www.etl.noaa.gov/technology/archive/ronbrown/

CNS

SPS

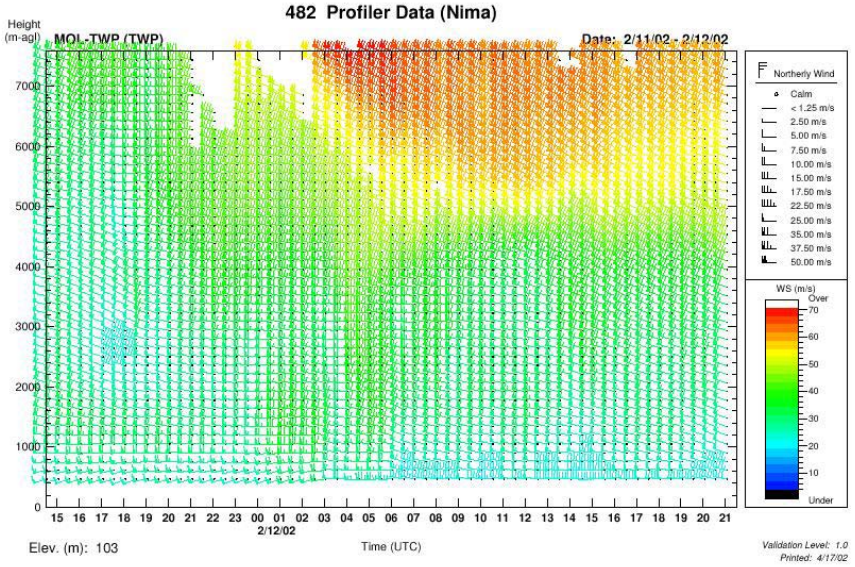


Ground clutter standard processing



Ground clutter Casper processing

NIMA



Ground clutter Nima processing

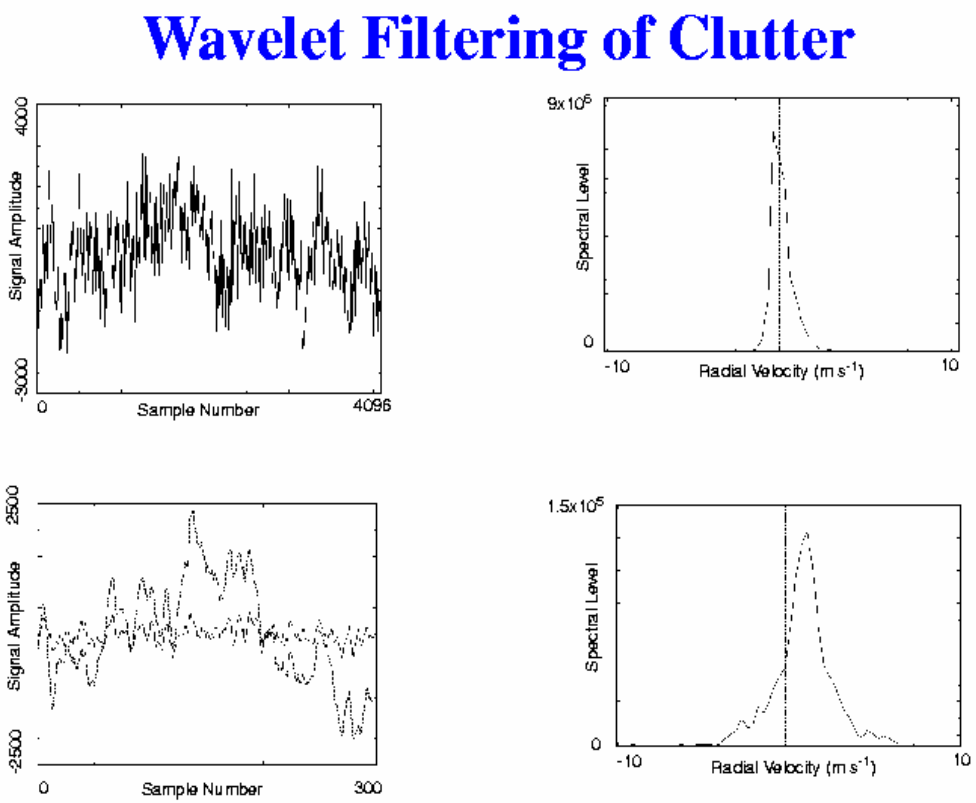
Images courtesy of:

Volker Lehmann Volker.lehmann@dwd.de

Motivation for "Improved" Signal Processing

- Experience with standard signal processing has uncovered deficiencies. Data quality degraded due to clutter, although correct information is in raw data.
- New awareness of problem complexity. Real data can have spectra with intricate detail and enormous dynamic range.
- Enormous increase in computational power (real-time and off-line).

Wavelet Filtering



Jordan et al., JTech 14 (1997)

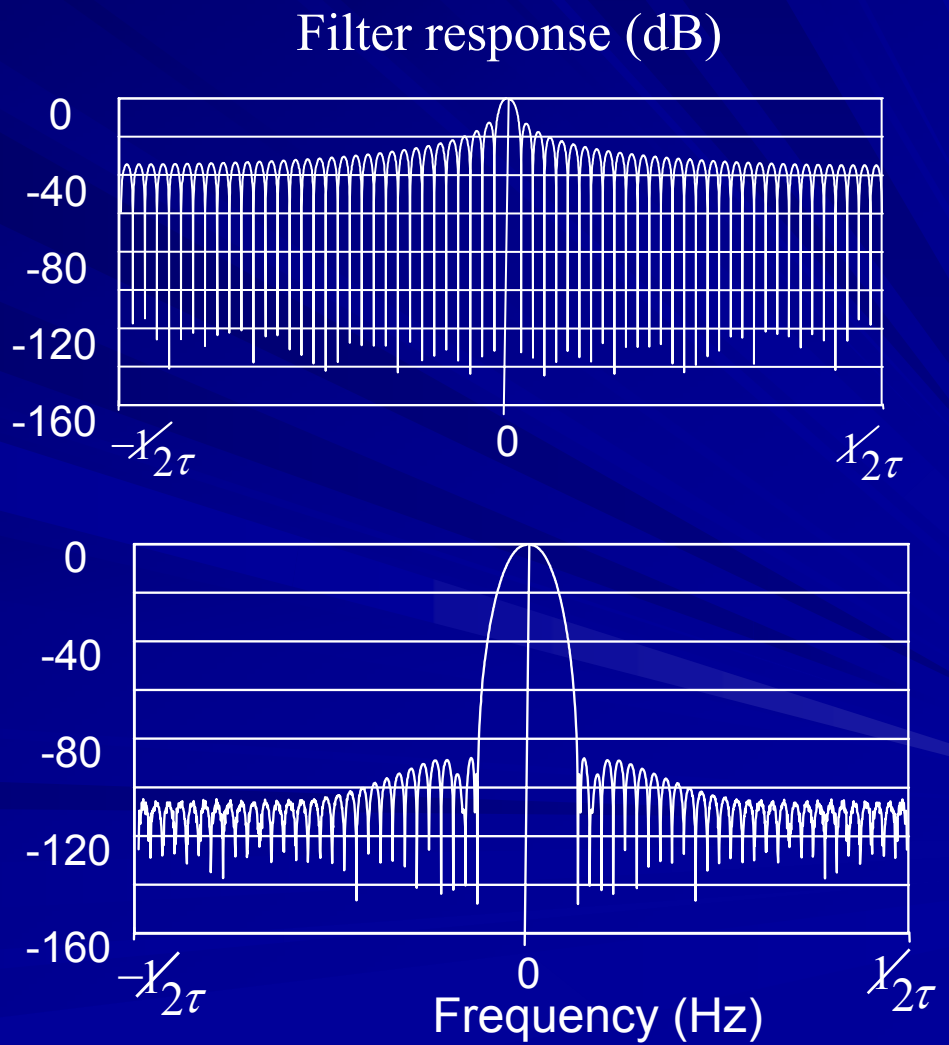
Modified Coherent Averaging

A. No coherent averaging

or

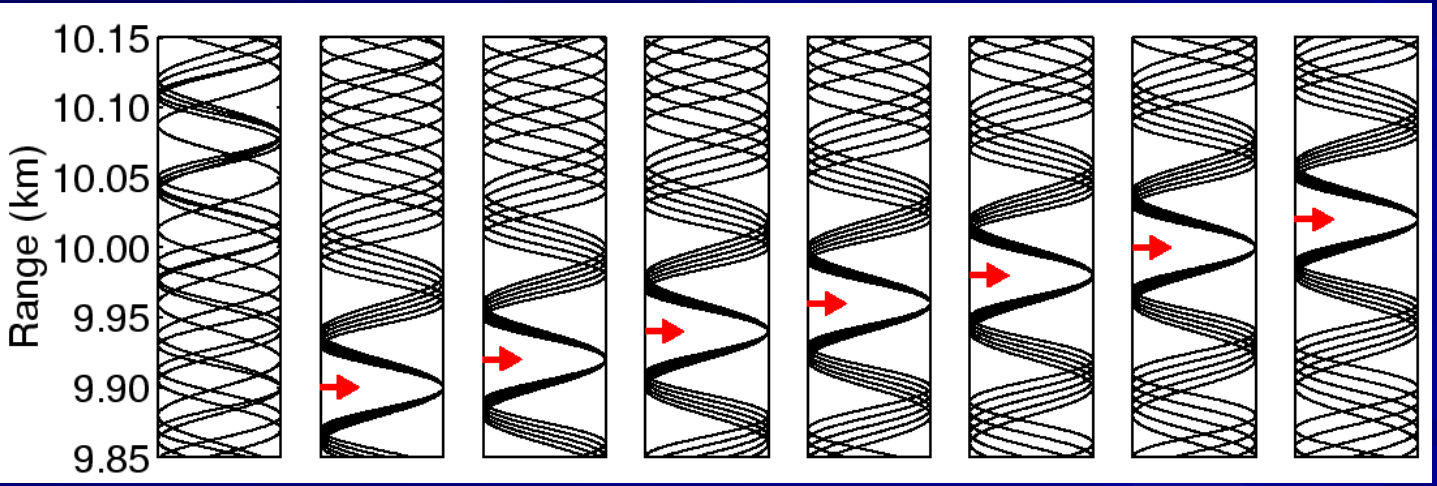
B. Blackman-Harris (or other) window, rather than a boxcar average.

Wilfong et al., JTech 16 (1999)



Range Imaging (RIM)

A technique of combining signals from shifted frequencies to reconstruct the atmospheric structure in range within the radar volume



- $s_i(t) = e^{-j\,2\,k_i\,R}$

- **Signals from shifted frequencies can be added coherently at a specific range by introducing proper phase shifts to the signals**

Image courtesy of Phillip.Chilson@noaa.gov

Experiment Results: April 10, 2001

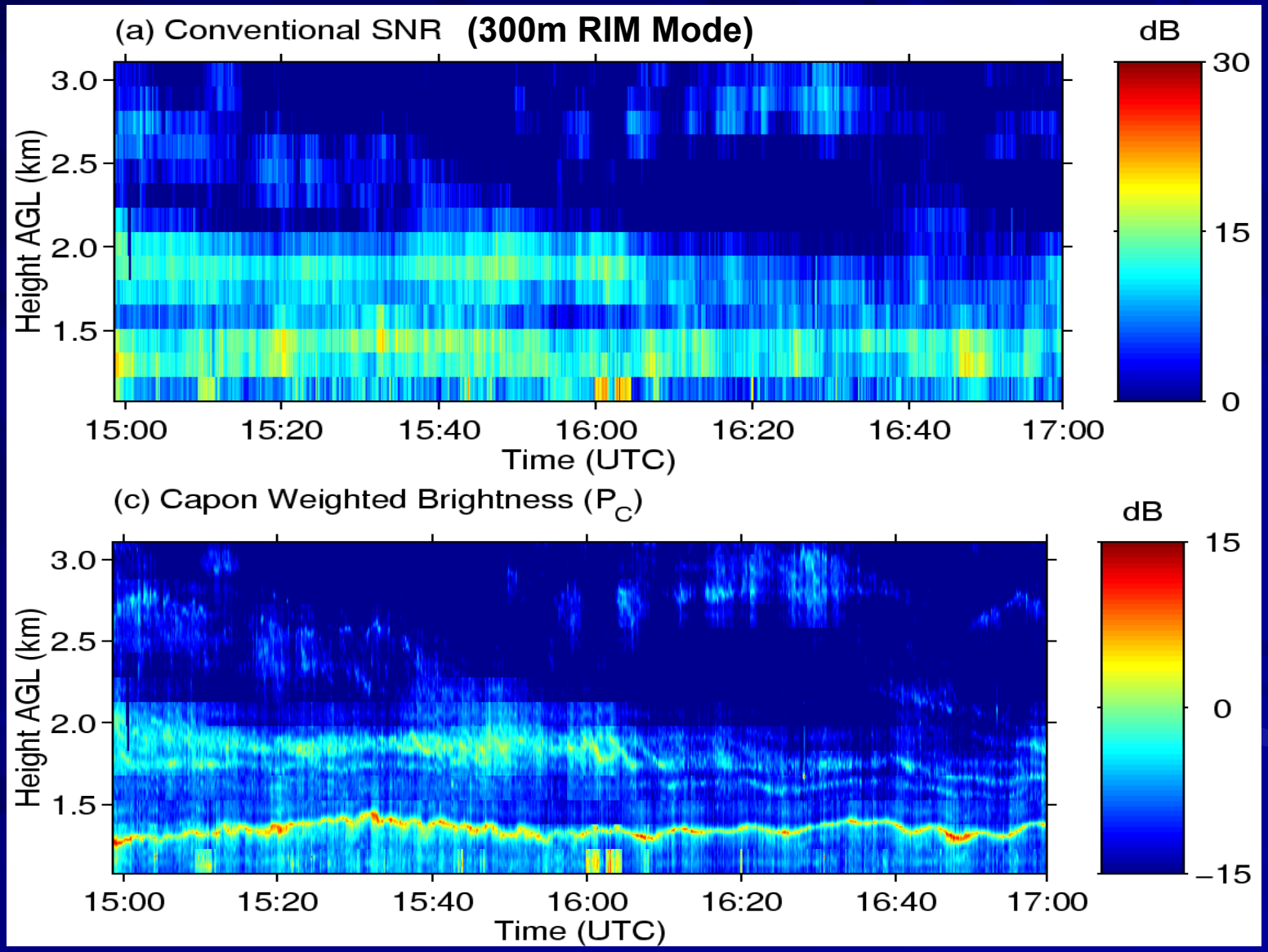


Image courtesy of Phillip.Chilson@noaa.gov

High-Resolution RIM

Mode 3: Range Resolution of 75m and Four Frequencies with Max. Spacing of 4 MHz⇒ **75m RIM Mode**

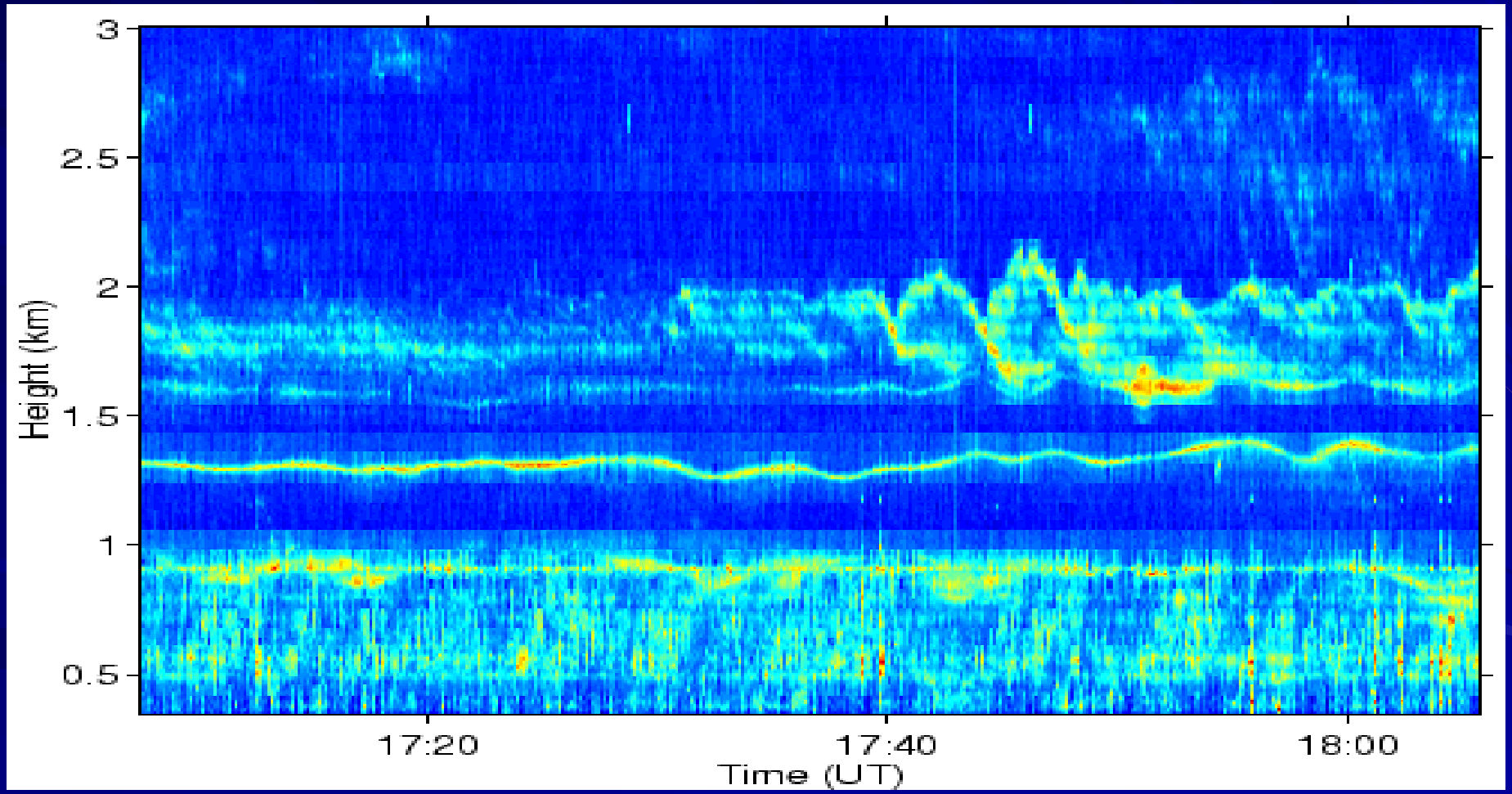


Image courtesy of Phillip.Chilson@noaa.gov

MAPR RIM: September 9, 2001

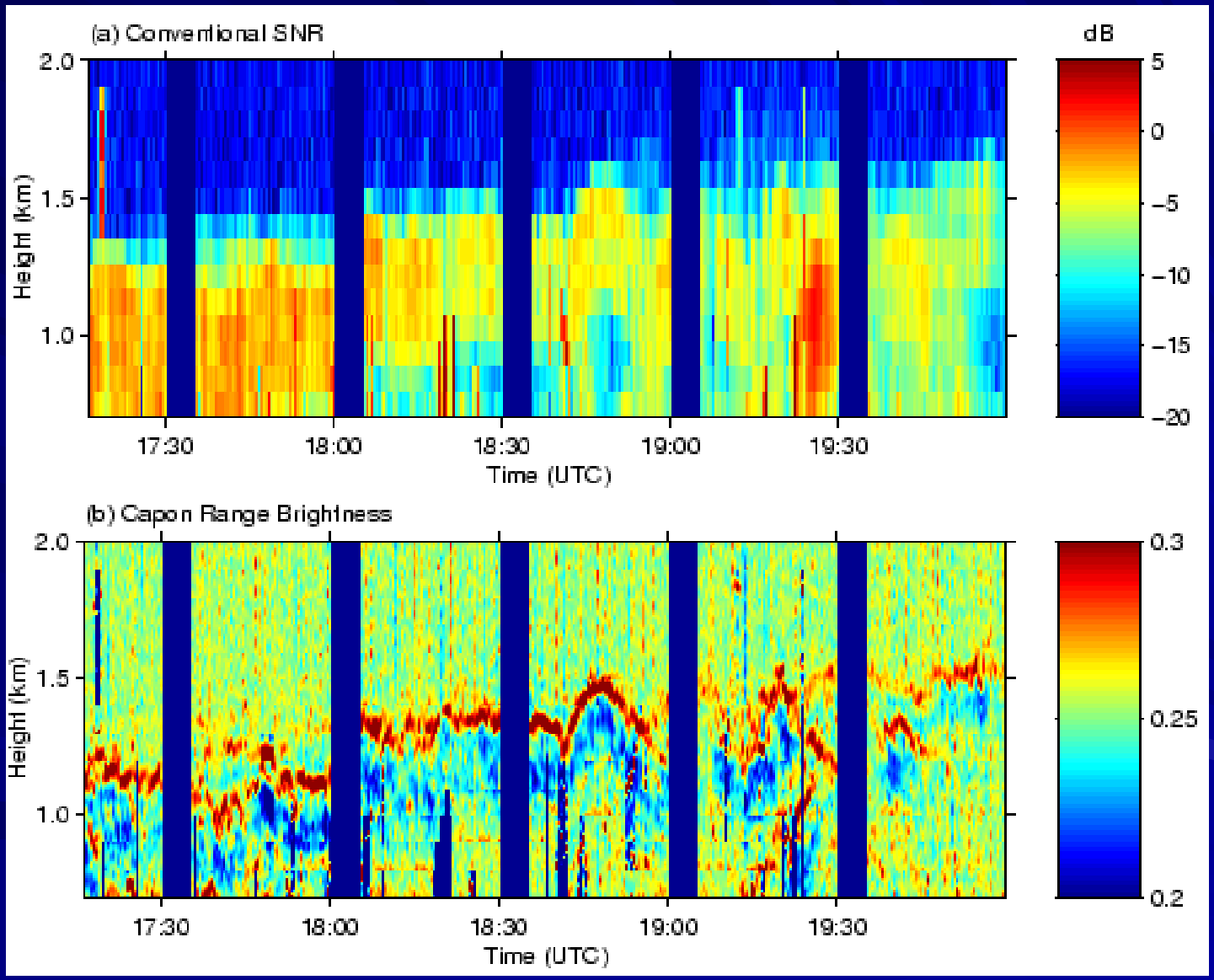


Image courtesy of Phillip.Chilson@noaa.gov

Summary

Time Domain processing

- Improved generation of Doppler spectra
- Lack of technical capabilities for online processing in existing systems
- Nonlinear filters (Wavelet) need further theoretical work
- Good theoretical foundation for linear digital filters, DFT, window functions

Spectral Domain processing

- No solid theoretical foundation for a-priori information
- Complex software packages implementation and algorithm testing
- More difficult to show data quality improvements than originally thought
- Many tuning possibilities…advantage or drawback
- Long term evaluation necessary
- Problems with current packages wind shear, birds, low SNR

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The End

Notes:

Much can be gained from using:

- ***Simple, proven filtering techniques***
- ***Height and time continuity information***
- ***Global image processing***

Caution: These ideas can not necessarily be used together

Also: Hardware improvements could also address the problems of clutter and aliased RFI